INSTITUTION NOTES

November, 1941

Fixtures

November 22—Edinburgh Section. Lecture by Mr. Stanley Murray on "Electrical Deposition of Metals and the Anodic Treatment of Aluminium."

November 26—Sheffield Section. Lecture by Mr. A. E. Morrison, M.I.P.E., on "The Manufacture of Precision Measuring Tools."

November 29—Manchester Section. Lecture by Dr. Geo. Schlesinger on "Surface Finish."

December 6—London Graduate Section. Annual Meeting and Lecture at Institute of Mechanical Engineers, 3 p.m.

December 12—London Section. Address by Mr. — Dudding on "Inspection Methods" at Institute of Mechanical Engineers. 2-30 p.m.

December 12—North-Eastern Section, Newcastle-on-Tyne. Lecture by Mr. A. Chilton, M.I.P.E., on "Drop Forgings."

December 19—Meeting of the Council, London.

Annual General and Extraordinary General Meetings

The Twentieth Annual General Meeting of the Institution was held on November 6, 1941, at London Headquarters, when the results of the annual elections to the Council were declared, the annual report and accounts adopted, the auditors re-elected, and a vote of thanks passed to Lecturers and Section Hon. Secretaries for their services during the past 12 months.

At the Extraordinary General Meeting, which followed, the alterations to the Articles of Association, approved by the Council, dealing with the revised conditions for election to the grade of Associate, were adopted. These were outlined in last month's "Notes" and in *The Technical Bulletin* for October, and have now come into effective operation.

Subscriptions Received for Research

Since the list in last month's "Notes" the following subscriptions for the work of the Research Department have been received:—

	£	s.	d.
Brush Electrical Engineering Co. Ltd.	52	10	0
Holman Bros., Ltd.	50	0	0
G. D. Peters & Co. Ltd....	50	0	0
Reavell & Co. Ltd....	26	5	0
Aladdin Industries, Ltd.	25	0	0
T. H. & J. Daniels, Ltd.	25	5	0
Thos. Ryder & Sons Ltd.	20	0	0
Leytonstone Jig and Tool Co. Ltd.	5	5	0
Wallace & Tiernan, Ltd....	5	5	0

Since the beginning of June of this year the total subscriptions received from firms and members, and acknowledged in these "Notes," have been as follows:—

	£	s.	d.
Acknowledged in July "Notes"	1,728	0	6
,, ,, August "Notes"	611	15	0
,, ,, September "Notes"	366	15	0
,, ,, October "Notes"	70	0	0
,, ,, November "Notes"	259	10	0
	£3,036	0	6

Considering that there has been no formal or official appeal for subscriptions issued by the Institution, this steady progress over a few months is very satisfactory. It is due entirely to the individual initiative of members, who, at the suggestion of Headquarters, have asked their own firms to support our research work, or have invited Headquarters to do so. The Institution is greatly indebted to all those members who have helped so successfully in this matter.

There is still, however, an enormous reserve of firms as yet unapproached for support. *Only 39 firms are represented in the lists making up the total shown of £3,036. 0s. 6d.*, and, of course, there are still hundreds of other firms who will, no doubt, be willing to give their support.

At this stage, rather than issue a formal appeal—which would be necessarily of rather an impersonal nature—it is probably well to continue the policy of seeking support through the good offices of our members.

Members, therefore, who have not yet taken action in the matter, and who are willing to approach their companies, or who think that the Institution might do so, are kindly requested to communicate with the General Secretary, when the necessary arrangements for such an approach will be made.

Specimen Syllabuses for Higher National Certificate Courses in Production Engineering

The Joint Committee dealing with this subject have prepared notes and specimen syllabuses for the general guidance of Colleges contemplating the inauguration of Higher National Certificate Courses in Production Engineering. The Board of Education is to circulate these shortly to the Principals of Technical Colleges. It is also intended to publish them in our *Journal*, together with memoranda showing what the American Society of Tool Engineers is doing along somewhat similar lines.

The specimen syllabuses cover the following subjects: Workshop Technology; Properties and Strength of Materials; Metallurgy; Theory of Machines; Jig and Tool Design; Machine Tools; Metrology (Technical Measurement); Press and Sheet Metal Work; Plastics Technology; Press Work—Plastics; Welding Processes; Hot Stamping and Forging; and Foundry Processes.

Specimen syllabuses for the Post Higher National Certificate Stage are being prepared for the following subjects: Industrial Administration; Scientific Management; Motion and Time Study; and Specifications and Estimates.

Intensive Training Scheme (Engineering)

The attention of all members and of Affiliated Firms is drawn to an important circular notice issued on November 10 by Lord Hankey, marked "For the information of Engineering Firms."

This deals with the new Intensive Training Scheme for employees of Ordinary National Certificate standard or its equivalent. The Course will be of six months' duration, and, in addition to free tuition, employees selected for training will have the status of holders of awards granted by the State, and will receive allowances at the following rates: £160 p.a. in London and £130 p.a. outside London, if living in lodgings, and £90 or £75 p.a. if living at home.

About 23 Colleges are listed for Production Engineering Courses under the scheme. Members interested in putting forward candidates should approach their own Firms for fuller particulars. All employees will be returned to their Firms at the end of the six months' training.

Addresses Wanted

MEMBERS: H. J. Armstrong, L. Clayton, H. J. Graves, W. Hickman, A. C. Ledingham, J. W. Messinger, H. F. L. Orcutt, A. Robinson, W. H. Spivey, E. E. Tournier, H. F. Varley, L. H. Wadsworth.

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INTERMEDIATE ASSOCIATE MEMBERS: J. A. Crofton, W. R. Gray, A. Newcombe, E. C. A. Stinton.

ASSOCIATE: A. Shaw.

GRADUATES: I. D. Bayley, A. Demeny, M. D. Doulton, G. Fooks, R. T. Johnson, J. Lee, E. Mells, B. F. P. Membery, L. F. Redfern, R. K. Snowball, H. H. L. Ward.

STUDENTS: E. F. Constable, P. W. Lygo, G. D. Parker, E. E. Robertson.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "The Journal" should not be taken as an indication that they are necessarily available for export.

SOME APPLICATIONS OF OPTICS TO ENGINEERING

*Paper presented to the Institution by Mark H. Taylor (Member), and read at six Local Section Meetings.**

WHEN new and unusual methods are introduced into any well-established field of technology their appearance inevitably results in a good deal of controversy and diversity of opinion. This has proved to be just as true of optical instruments in engineering as of anything else, for while many engineers still regard such devices with considerable mistrust, others have found them so useful and convenient in practice that they tend to put implicit faith in the readings of any optical instrument which happens to come into their hands. Neither of these extreme views is really justified, for while optical instruments can be immensely valuable, each is designed for specific conditions. Where these conditions do not exist the results may be completely misleading.

Now the principal object of such optical devices as are used by engineers is to obtain an enlarged image of the object being examined, so that detail may be more easily seen and measurements made. Common devices are: (1) magnifiers; (2) microscopes; (3) telescopes; (4) projectors; (5) cameras. There are, of course, many other instruments available for engineers, but their optical sections are nearly all based on one or more of these five devices.

Magnifiers

The normal eye is capable of seeing clearly (i.e., focusing) any object which is more than 10in. away. A far distant object appears small, and detail is therefore ill-defined. As the object is brought nearer and nearer it appears to become larger and larger, and the detail becomes clearer until the object is 10in. from the eye. If it is brought still nearer, the eye, because of its own natural limitations, is incapable of seeing it clearly, but if the eye could see clearly at this shorter distance the object would appear larger and still more detail would become apparent. The magnifier enables the eye to see clearly an object less than 10in.

(Vol. XX, No. 11, November, 1941.)

* *Birmingham, July 23; Manchester, May 26; Leeds, February 24, 1941; Leicester, December 12; Ipswich, March 19; Camborne, March 6, 1940.*

away. In other words, the simple magnifier (Fig. 1) has the effect of making an object of length "A" appear to have a length "B." If "B" is five times "A," the magnification is said to be $\times 5$.

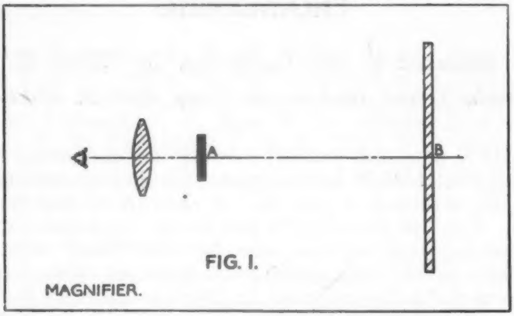


FIG. 1.
MAGNIFIER.

Microscopes

The microscope is, in effect, two superimposed magnifiers—one is called the eye-piece, the other the objective. (Fig. 2.) Here "B" is still, for example, $5 \times$ "A," but "A" is itself, for example, $5 \times$ "C," "C" being the object viewed. In this case the magnification of the whole system is $5 \times 5 = 25$. It is sometimes convenient to place a graticule, or glass scale, at "A." If

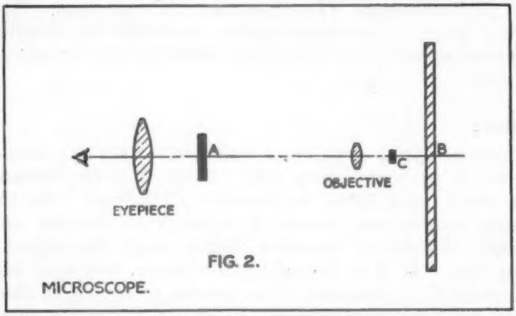


FIG. 2.
MICROSCOPE.

this is done the scale appears to be superimposed on "A," and the one may be used for measuring or locating the other. If the glass scale is not accurately located at "A," then movement of the eye sideways appears to introduce relative movement of the scale in relation to "A." This error is known as parallax.

Telescopes

The telescope may be regarded as a type of microscope adapted for viewing distant objects.

Projectors

In this case the optical system consists of a lens which produces an image (usually enlarged) of "D" (the object) at "E."

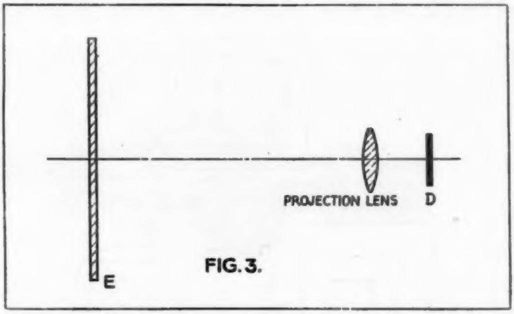


FIG. 3.

(Fig. 3.) At "E" there is a screen which can be viewed with the unaided eye.

Cameras

These are similar to the projector, except that a photographic plate or film is used at "E" (Fig. 3) instead of a screen.

General Considerations

Sometimes the image produced by an instrument is erect (right way up), sometimes inverted (upside down), but in either case the design must be such that *all* the rays of light which leave any one part of the object and pass through the lens system reach the appropriate part of the image. For them to do otherwise would obviously cause confusion. To achieve this result the foregoing instruments generally contain a series of polished glasses mounted truly about an axis. Each glass is of a specified material and shape, and it must be correctly related in position to the rest of the series.

So that some of the problems involved in the design of optical instruments may be appreciated it is well to review very briefly the means at the disposal of the optical instrument designer, and consider something of what his job entails. The media with which he deals are light, glass, and air. When light travels from one transparent medium into another of different density its path is deflected. White light is made up of many colours. Each coloured light behaves differently. The optician uses many kinds

of glass. Each kind of glass affects the light differently. What is more, each kind deals in different ways with light of differing colour.

Examination of a printed sheet through a simple magnifier will show up several obvious defects in its performance. The image is clearly defined only near the axis of the lens; further out the lettering becomes confused, surrounded with colour fringes, and distorted. (Fig. 4.)

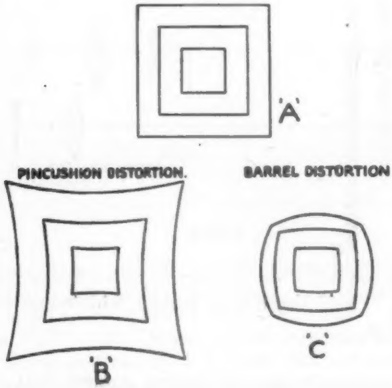
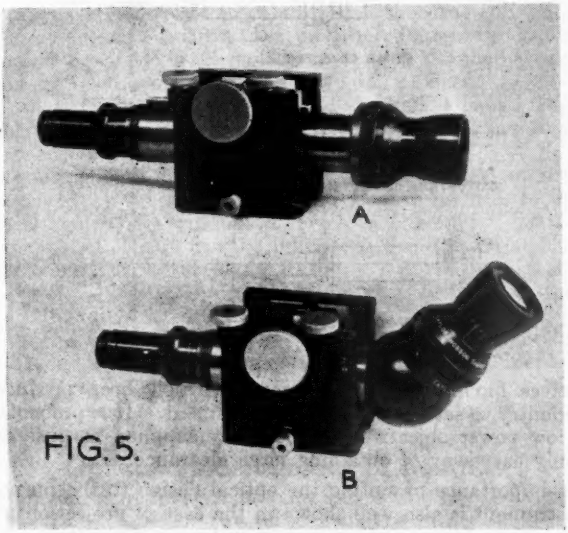


FIG. 4.

A small simple lens will only give a clear image if used over a small angle and with light of one colour. Even then the image is distorted and is not sharply focused in a plane. If the performance is to be improved the aperture or effective size of the glasses may have to be increased, and the lens "corrected" to: (*a*) bring rays of all colours to a common focus (colour correction) to avoid colour fringes; (*b*) make the lens focus in a plane (flatness of field), so that the edges and centre of the image are clearly defined simultaneously; (*c*) make the image free from distortion so that the image is a true reproduction of the object being viewed. These "corrections" are made as the result of intricate mathematical calculation, and they are achieved in the lens by the addition of glasses of the correct form and material placed in the system in their correct positions. Each successive step in the design, however, has to be made without upsetting conditions previously satisfied. The range of types of glass available is limited; some of them stain badly, and must therefore be fitted on unexposed parts of the optical system. The surface of the

polished glasses is normally spherical or flat; other types of surface are extremely difficult to produce with sufficient accuracy, and are therefore very expensive*.

As the final result is at best a compromise, the importance of each condition must be assessed so that the designer is free to sacrifice unimportant conditions in favour of more important ones. For example, although for many purposes a simple and relatively cheap type may be suitable, whenever a microscope is



Engineer's microscope, fitted with distortion-free objectives.
A—" Straight-through " model, which gives an inverted image.
B—Bent model, which gives an erect image.

used to measure the shape or size of an object by comparing what is seen through the microscope with a scale graticule, thread form graticule, or the like, placed within the microscope (at "A," Fig. 2), then the objective of the microscope must be "corrected" for distortion.

** Lens glasses of good quality are normally polished until they are true to form within a wavelength of light, which is approximately one fifty-thousandth of an inch. In special cases this limit may be only a few millionths. A millionth of an inch is difficult to visualise. Imagine a cheque for £2,000 cashed in halfpennies. There would be a million of them, and laid edge to edge in a straight line they would stretch 15 miles. The unit of "one millionth" divides the inch in the same ratio as a halfpenny divides 15 miles.*

A special requirement of an engineer's microscope (Fig. 5) is that it shall have a large working clearance between the objective and the work. In the conventional type of objective this clearance becomes very small if the magnification is high. If it is desired to view, for example, the trued form of a grinding wheel, the objective would foul the wheel (Fig. 6). Special distortion-free

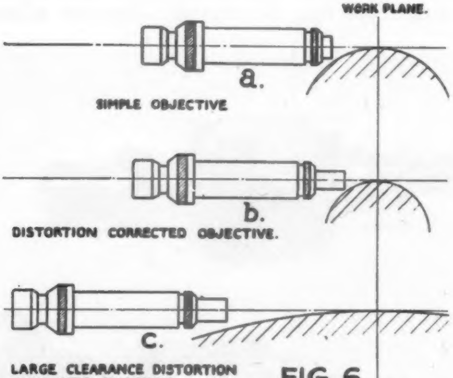


FIG. 6.

objectives having large clearances have now been produced in this country to satisfy the above requirement. It is probable that very low power objectives are normally supplied because this is the only easy way of obtaining large clearance.

The importance of suiting the optical design to the purpose of an instrument is also well shown in the case of projection lenses. To take an ordinary cinema projection lens and use it in a profile projector would produce most misleading results.

A cinema lens is designed to pass the greatest possible amount of light, and to give an image which shows no colour fringes from a thin flat original (the film). Such lenses almost always introduce considerable distortion of the image towards the edge of the screen, but for the projection of pictures in cinemas this defect is of no importance. To correct such lenses for distortion would involve sacrificing some more important quality.

In profile projection, however, the purpose of the instrument is to check the forms of thick objects with the greatest accuracy possible. Distortion must be reduced to such low limits that the screen image is a faithful copy of the original within normal tolerances, and to do this brilliance of image has to be sacrificed.

Types of Measurement to which Optics can be Usefully Applied

These divide themselves into three main classes: (1) Measurement of length; (2) Measurement of angles; (3) Measurement of irregular contours.

The mechanical means for making these measurements are well known. Most of them have stood the test of time, but, in so far as they depend on elements which wear out, they have to be frequently checked and adjusted. This checking and adjusting is a very expensive business; it is either done very frequently for the sake of safety, or, if neglected, much of the shop tolerances is eaten up by the measuring and gauging devices.

The micrometer wears rapidly; and the height gauge, because it does not establish a known pressure between its jaw and the work, needs to be handled with considerable skill.

The mechanical dividing head can have many sources of inaccuracy; it is subject to wear, and when worn it is incapable of adjustment. The graduated level, or clinometer, is a very convenient tool, but it has the limitation that measurements are made from a horizontal plane which is not necessarily related to the work. The sine bar is not a very convenient tool in unskilled hands.

As to the mechanical means of measuring irregular shapes, these depend on those instruments which have been mentioned, and the process is frequently tedious.

Optical means are in many cases available for making the three fundamental types of measurement.

Optical Measurement of Lengths

For the measurement of lengths and diameters the specimen may be placed between two anvils, under a standard pressure, as in the micrometer or measuring machine, and the separation of the anvils can be read off on an accurately divided scale by means of a microscope. Neither the microscope nor the scale wears out. The zero mark may be placed either in the same plane as the scale, or it may be mounted within the microscope. The scales used for this type of measurement may be so fine that the graduations can hardly be seen with the naked eye, and their accuracy is in the order of a hundred-thousandth in four inches.

A system based on this principle has been adopted on the Jig Borer produced by Société Genevoise, and since wear in the motive screw does not result in inconsistency of readings, continued accuracy over long periods becomes possible, yet even such a system of measurement as this has to be designed with great care or it may suffer from the differential expansion of scale, machine, and specimen, with temperature.

Optical Measurement of Angles

A microscope and an accurately divided optical scale do not wear out. The optical dividing head is therefore a great favourite with engineers (Fig. 7). In such an instrument it is very necessary that the scale is accurately centred on its spindle, and that its axial bearings are beyond question. If in a device of this sort a sector of a disc is used instead of a complete disc for the scale,

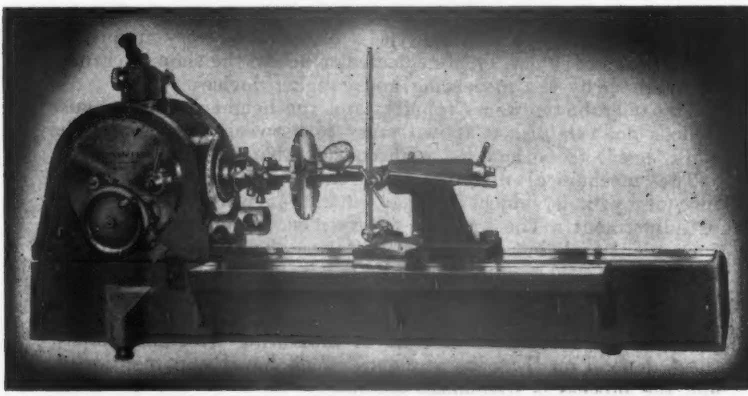


Fig. 7—Optical Dividing Head.

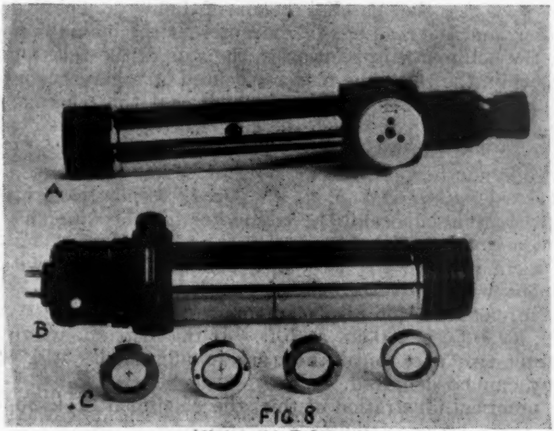
the question of differential expansion may still cause difficulties in practice.

There are, however, a large number of types of angular measurement for which an ordinary dividing head is in no way suitable, and in these fields of work some highly specialised instruments have been designed. The surveyor, for example, uses a dividing head in conjunction with a telescope in his theodolite. It may be of interest, particularly to those who think that accurate instruments are made only on the Continent, to know that the circular optical divided scales regularly made in this country and mounted in theodolites have a guaranteed accuracy of one second of arc, which represents an error of 1in. in 3 miles.

As soon as the distances involved in a measurement become considerable, optical methods are immediately adopted on account of their convenience.

Where it is required to assess the alignment of two surfaces, holes, or bearings, which are widely separated, as, for example,

in the case of large electrical generators, in ship propulsion gear, or in the interchangeable components of aircraft fusilages, two basic measurements are needed: (*a*) inclination of the two axes (this is an angle measurement); (*b*) relative displacement of the two axes (this is a linear measurement).



Alignment Telescope.
A—Telescope proper. B—Collimator. C—Targets.

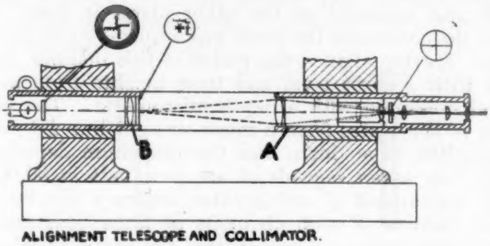


FIG. 9.

Alignment Telescope

Such measurements may be made with an Alignment Telescope. This instrument comprises two units—the telescope proper and a collimator (Figs. 8 and 9). (A collimator is a device for projecting a parallel beam of light.)

The optical systems of both instruments are accurately centred in ground steel tubes. The two instruments may be mounted

directly or by means of concentric adapters or other devices so that they face one another, and the observations which are made through the telescope are an indication of the amount by which two instruments so located depart from alignment with one another.

Mounted on the side of the telescope is an adjusting knob by which the telescope is made to focus either at infinity (in which case it receives the parallel beam of light projected by the collimator, and the readings taken represent the inclination of the axis of the collimator in relation to the axis of the telescope), or, alternatively, the telescope may be focused on a glass scale placed at the front of the collimator (in which case the readings taken indicate the amount by which the centre of the scale is displaced from the axis of the telescope). The readings are quite independent of one another and cannot be confused.

Other scales or targets may, if desired, be placed at intervals between the telescope and the collimator for checking the alignment of a number of holes.

The inclination of the two axes can be measured with this instrument within six seconds of arc, i.e., one part in 30,000, or .0004in. per foot, and displacements can be read to an accuracy of .01in. at 50ft., or .003in. at 10ft. If the instruments are used for setting two axes until they are in alignment, still greater accuracy can be achieved.

As a practical illustration of this, the Alignment Telescope was used to set a series of plates in a row over a distance of 60ft. such that their surfaces lay in a common plane. The telescope was mounted on one plate, and observations made upon the collimator unit mounted on the other plates in turn. At each position of the collimator the plate was adjusted until the readings were zero. Having aligned the plates in this manner, they were all tested with a spirit level and their heights from a common water level measured with a depth micrometer. The maximum divergence of the plates from a mean straight line did not exceed two-thousandths of an inch, and the maximum departure from parallelism was seven seconds of arc (one part in 30,000).

Another instrument of still greater accuracy can be used for testing the flatness of such elements as lathe beds and surface plates; the straightness of long holes; the straightness of travel of machine elements; the squareness of one machine slide to another; the parallelism or squareness of a machine spindle to its table; in fact, the relative location of surfaces and axes in all types of mechanisms.

Autocollimator

All these measurements are based on the tilt of a mirror suitably located on one of the elements, the tilt being measurd by an

instrument known as an Autocollimator (Fig. 10), located on the other element.

The autocollimator may be regarded as an alignment telescope and collimator combined in one instrument; that is to say, the

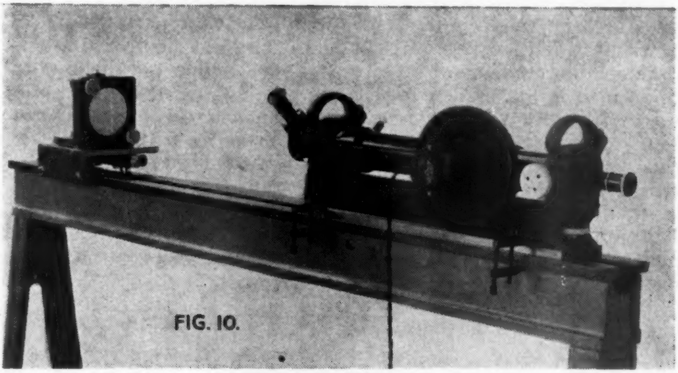


FIG. 10.

Autocollimator.

Autocollimator projects a parallel beam of light which is reflected from a mirror placed at any convenient distance back into the instrument by which it is observed, and the measurements so taken indicate the amount by which the reflected beam fails to be parallel with the projected beam. The measurement is therefore an indication of the amount by which the mirror fails to be normal to the instrument axis.

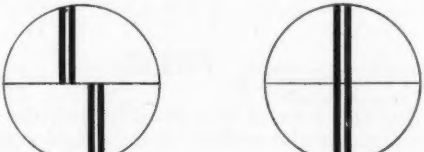
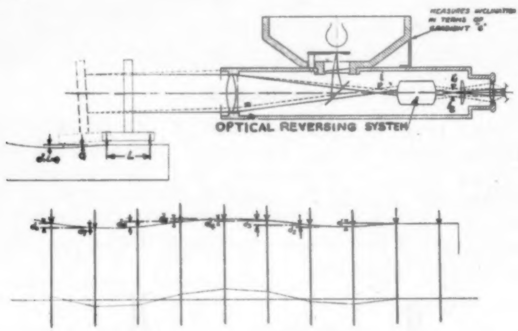


FIG. 11.

AUTOCOLLIMATOR COINCIDENCE SETTING

Readings in the instrument are taken by looking through its eyepiece and then adjusting a drum until broken lines come into coincidence, that is, in line with each other (Fig. 11). The amount by which the mirror is tipped at any particular setting is then read off on the graduated drum.

The sensitivity of the Autocollimator is interesting. The drum by which the images are made to coincide carries a scale, each division of which represents a change in gradient of one part in a hundred-thousand, or one ten-thousandth of an inch in 10in. There is no difficulty in setting the drum consistently to a fifth of a division, while after some practice consistent setting to a tenth of a division becomes possible. The last figure represents a detectable gradient of one in a million, or one ten-thousandth of an inch in 8ft. Clear images are obtained when the mirror is up to 70ft. from the telescope unit, and the above values for consistency in setting are possible up to at least 18ft. Beyond this distance the stillness of the air is the limiting factor in the sensitivity of the instrument. The range of the drum scale is ± 50 units, thus dealing with gradients up to ± 1 in 2,000, or 1/20th of an inch in 8ft. Because of this high sensitivity a small finder telescope is fitted to the main unit in order to facilitate setting up.



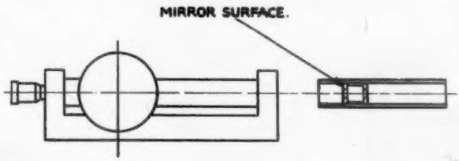
AUTOCOLLIMATOR STRAIGHTNESS TEST FIG. 12.

For measuring the flatness of a machine bed the instrument is placed at one end of the surface, or on a rigid support in line with the bed, while the mirror on its small carriage is placed at various positions on the bed. Readings are taken at distances along the surface equal to multiples of the distance between the front and rear feet on the small mirror carriage, so that consecutive sections of the surface are tested for inclination to the axis of the instrument. A graph can then be drawn on squared paper showing the flatness of the surface. (Fig. 12.)

It is true that this can be done with an engineer's level, but where the straightness of a vertical or inclined face, such as the front of a lathe bed or the surface of a vee, has to be measured

the level is of no value. The autocollimator can be inclined to read flatness at any angle. The readings are taken in exactly the same way as has been described for a horizontal surface.

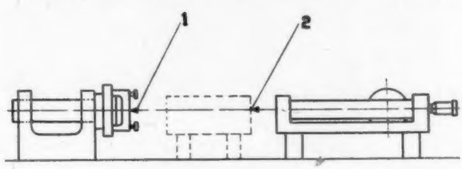
A very useful application of this instrument is the measurement of straightness of long holes. All that is required is a small plug which fits the hole (Fig. 13), this plug having one end polished



AUTOCOLLIMATOR: STRAIGHTNESS OF HOLES.

FIG. 13.

accurately normal to the axis of its cylindrical portion. The plug is relieved at the centre so that each end fits the bore. It is easy to check the accuracy of the polished end, for if the plug is rotated in its hole, without moving it axially, and the reflected image is seen to move, then, obviously, the end is not normal to its cylindrical exterior. By pushing the plug its own length down the bore, step by step, and taking readings in the autocollimator in two planes, the straightness of the hole can easily be graphed. In producing the accurately lapped holes in the alignment



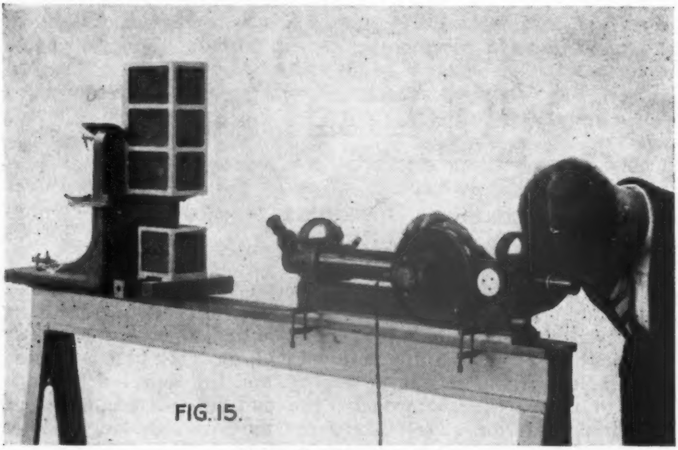
AUTOCOLLIMATOR:- PARALLELISM OF SPINDLE AND BED.

FIG. 14.

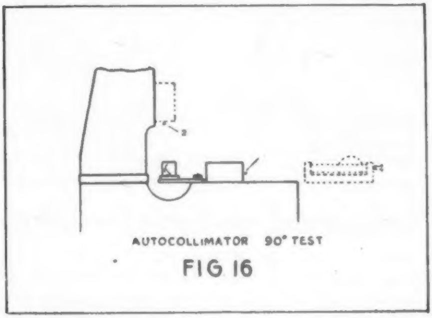
telescope bodies, this was found to be by far the easiest way of checking them. The works' grinding department regularly uses the instrument for this purpose.

It is not always easy to determine that a machine spindle is in line with the machine bed. (Fig 14.) If a mirror is mounted on the face plate of, for example, a lathe, and it is adjusted until

rotation of the spindle produces no movement of the reflected image, then the mirror is normal to the spindle axis. By comparing the readings from this mirror with those given by a mirror mounted squarely on the bed, any error in positioning of the spindle can be determined.



Autocollimator 90° test.



By the use of an optical square, which reflects a beam of light through an accurate right angle, readings of squareness of slides, spindles, and other elements to one another can be determined with great accuracy. (Figs. 15 and 16.)

The optical square has the particularly interesting quality of reflecting light through 90° even if it is not itself accurately located.

Optical Measurement of Irregular Contours

The instruments normally used are the Toolroom Microscope (Fig. 17) and the Profile Projector (Figs. 18 and 19).

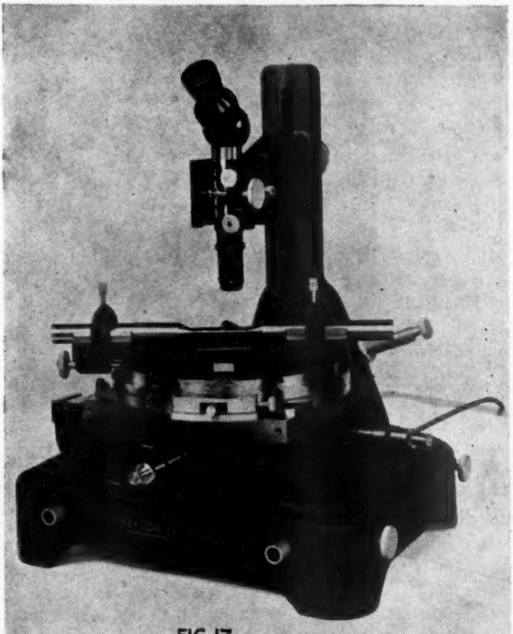
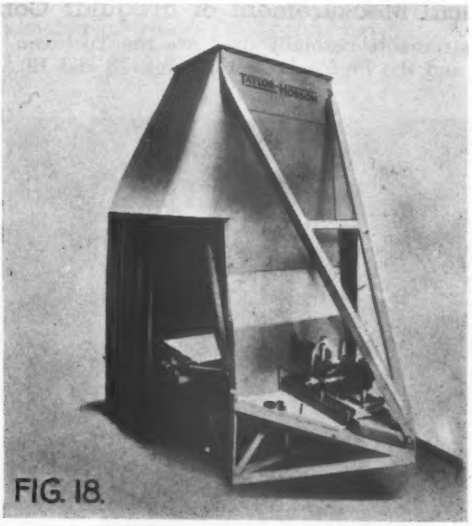


FIG. 17.

Toolroom Microscope.

The Toolroom Microscope (Fig. 17) consists of a floating table, the position of which is measured by two micrometers. This table may be surmounted by a "circular" table, by means of which the work may be rotated about a vertical axis. The table is adapted to carry the object being measured in some convenient manner. Above the table is a microscope of the type illustrated in Fig. 5. Within the microscope there may be graticules of

tooth forms or the like. Within the base of the instrument is an illuminating system for shining light upwards on to the lower



Profile Projector.

side of the object being viewed, so that the outline of the latter appears in sharp relief when viewed through the microscope.

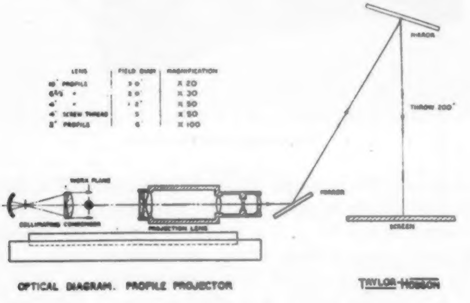


FIG. 19.

The Profile Projector (Figs. 18 and 19) is provided with similar means for holding the work, a similar illuminating system, and a projection lens by which an enlarged image of the object is produced on a screen. (Some projectors have a horizontal optical system forming an image on a distant vertical screen; others, as in the case illustrated, have mirrors by which the beam of light is bent up and down again on to a horizontal screen, which can be near that part of the instrument which carries the object.) Reduced to their simplest terms, and expressed diagrammatically, the two instruments are similar. In both, the object to be measured is placed in front of a lens " L " (Fig. 20), which lens

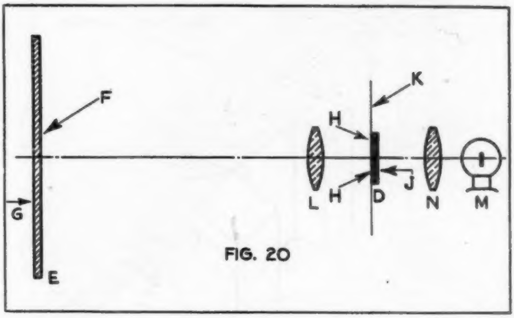


FIG. 20

produces in the plane " E " an enlarged image of the original " D." (In the case of a projector, " E " is a screen, which is sometimes viewed from the direction " F " if the screen is opaque, or from the direction " G " if the screen is translucent. In the case of a toolroom microscope, " E " lies within the microscope in such a position that it can be viewed from the direction " G " through the eyepiece (see " A," Fig. 2).)

The object " D," if it is to be clearly seen, must be brightly illuminated. This may be done by shining on to it a powerful beam of light in the direction " J." This light from the lamp " M " is concentrated on to the object by the condenser " N."*

The lamp " M," condenser " N," and lens " L " are really all part of the same optical system, and should be treated as such. *The lens " L," which must be very carefully corrected for distortion, cannot produce a sharp image at " E " of any part*

---

* *It is sometimes desirable to illuminate the object from the direction " H," but as in this case it is only light* reflected *from the object which forms the image in the plane " E," it is difficult to get images which are bright enough to be seen clearly on a projector. Such images can be recorded photographically or seen through a microscope.*

of the object " D " which does not lie in the focal plane " K." (The planes " E " and " K " must be parallel to one another and both are normal to the lens axis.) Therefore, while the projection of such thin objects as cinema films and microscope slides is relatively simple, the projection of such thick objects

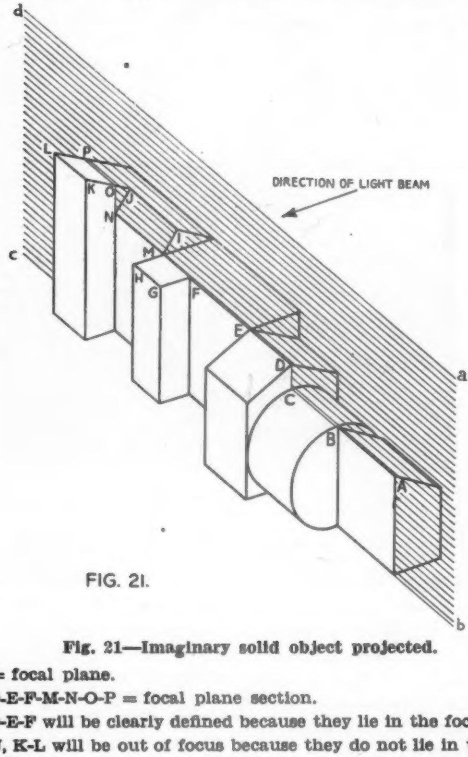


FIG. 21.

Fig. 21—Imaginary solid object projected.

a-b-c-d = focal plane.

A-B-C-D-E-F-M-N-O-P = focal plane section.

A-B-C-D-E-F will be clearly defined because they lie in the focal plane.

G-H, I-J, K-L will be out of focus because they do not lie in the focal plane.

as form tools, profile gauges, screw threads, etc., presents some complications, principally because any part of the thick object which is illuminated and does not lie in the focal plane " K " may produce an out-of-focus image on the screen and cause confusion.

To consider an imaginary solid object as illustrated by Fig. 21, in which a-b-c-d represents the focal plane, any illuminated part

of this object not lying in the plane a-b-c-d which can be seen by the lens will produce a confused image on the screen. Therefore the line A-B-C-D-E-F would be sharply defined, and G-H, I-J, K-L would be out of focus.

For convenience, the section of the object defined by the focal plane (i.e., the section A-B-C-D-E-F-M-N-O-P) may be called the *focal plane section.*

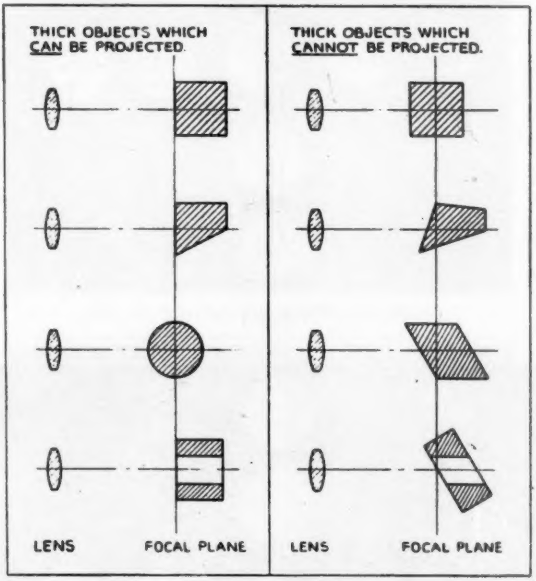
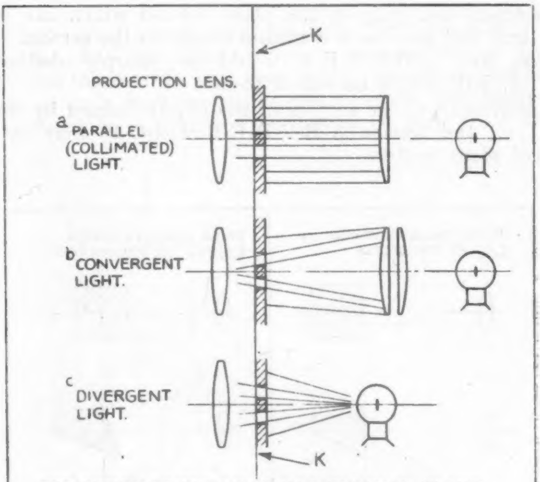


FIG. 22.

Fig. 22 shows diagrammatically a range of objects, some of which can, and others of which cannot, be projected.

As it is only the focal plane section which will produce a clearly defined image, and as any part of the object other than the focal plane section will cause confused images, it is desirable, so far as is possible, that the illuminating system should (*i*) illuminate the focal plane section; (*ii*) illuminate as little of the rest of the object as possible.

The illuminating beam can be of three types: collimated ("a," Fig. 23), convergent ("b," Fig. 23), or divergent ("c," Fig. 23).



PROJECTION OF TWO HOLES IN A PARALLEL PLANE

FIG. 23.

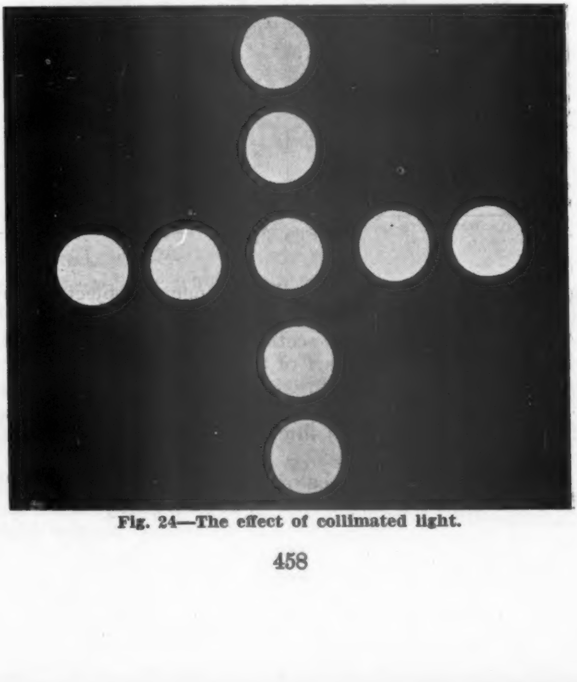


Fig. 24—The effect of collimated light.

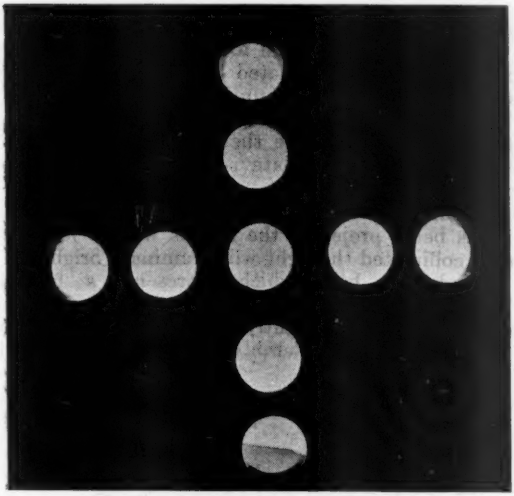


Fig. 25—The effect of convergent light.

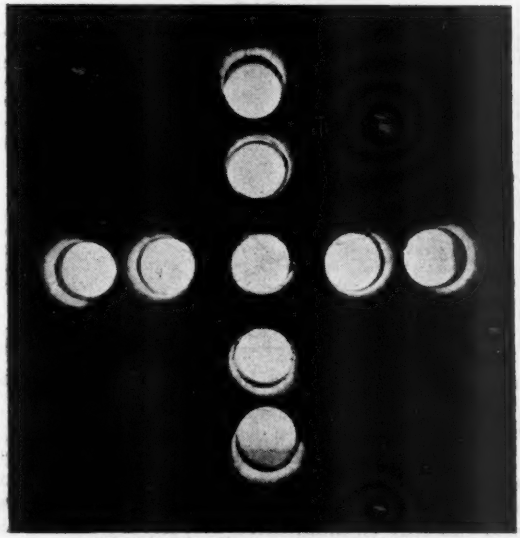
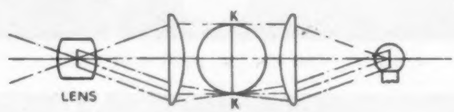


Fig. 26—The effect of divergent light.

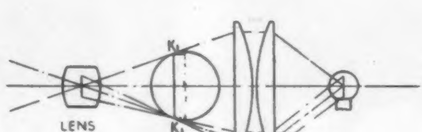
The illustration represents the projection of a parallel plate containing two drilled holes normal to the surface of the plate, and it will be seen that the collimated beam of light is the only one which will illuminate the circumference of both holes in the plane "K," which is the focal plane of the projection lens. Figs. 24, 25, and 26 illustrate the effects which will appear on the screen when a drilled plate is illuminated by each of the three types of beam.

If an uncollimated beam is used to illuminate a cylinder or ball which is being projected the results will be misleading. If the beam is collimated the light will illuminate brightly a portion of the cylinder or ball, which represents a full diameter ("K"-"K," Fig. 27), but if these objects are illuminated by convergent light, then the brightly illuminated portion corresponds with a measurement considerably less than the full diameter ("K_1"-"K_1" Fig. 28).



COLLIMATED LIGHT

FIG. 27.



CONVERGENT LIGHT.

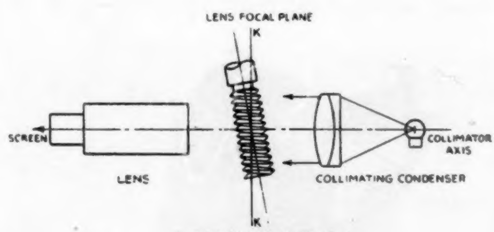
FIG. 28.

Collimated light is therefore important, and highly corrected profile projection lenses are designed for use with this form of illumination.

Screw Thread Projection

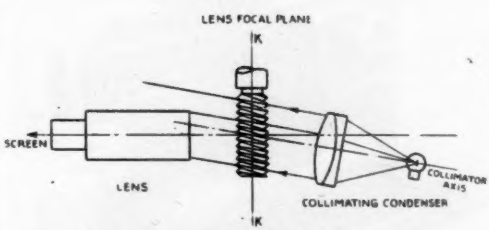
Screw thread projection presents some peculiar problems of its own, because in nearly all cases the helix angle is such that the thread can only be illuminated properly by shining the beam of light down the helix angle.

Bearing in mind that the focal plane of the projection lens is normal to the lens axis, it follows that if the lens and condenser (Fig. 29) are to remain in line with one another, as is the case with normal profile projection lenses, then the focal plane "K" (Fig. 29) will be inclined to the thread axis, and only part of the focal plane section will be illuminated, i.e., only one or two threads will be sharply in focus, while the threads on either side will appear to be out of focus.



1 SECTION NORMAL TO HELIX

PROJECTION OF SCREW THREADS. FIG 29.



2. SECTION ALONG SCREW AXIS.

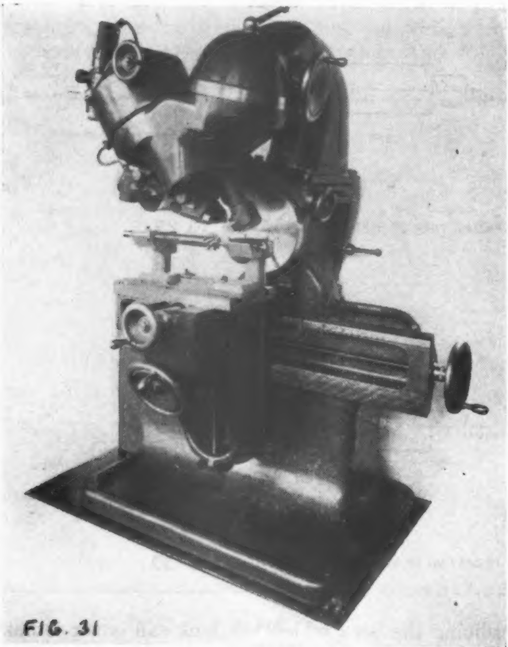
PROJECTION OF SCREW THREADS. FIG. 30.

By sacrificing the area which the lens can cover it has proved possible to produce lenses and microscope objectives corrected for distortion even when they receive a light beam which enters them obliquely (Fig. 30). These special lenses are known as *Screw Thread Lenses*, and they make possible the alternative method of screw thread projection, in which the screw, if its helix angle does not exceed 6°, can be mounted with its axis in the focal

plane of the projection lens, while the illuminating beam is swivelled round to shine down the helix. This gives sharp definition over the whole length of the screw thread, and, incidentally, the image corresponds with the section of the thread in its axial plane (which is the plane in which screw thread forms are defined).

Measurement of Some Irregular Shapes which cannot be Projected by Conventional Means

It has been shown that it is not possible to obtain a satisfactory projected image of the focal plane section at F-M, M-M, and



Section Projector.

O-P (Fig. 21) because (i) the area G-H-M-F will lead to out-of-focus images on the screen, so confusing the result; (ii) N-M, although it can be seen by the lens, is not illuminated by the light beam; (iii) O-P, although illuminated, is hidden from the lens.

Section Projector

There are very many objects in which one or more of these conditions make conventional projection impossible, as, for example, in the case of worm wheels, crown wheels, taper splines, and the like, and it is normally necessary to destroy such objects in order to measure their sections. Means have been devised for measuring the sections of such objects optically without destroying them. The instrument used is known as a Section Projector (Fig. 31). At present there is only one such instrument, and

FIG. 32

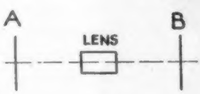


FIG. 33.

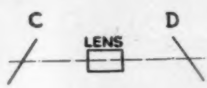
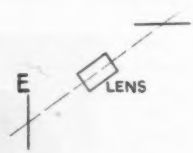


FIG. 34.



SECTION PROJECTOR PRINCIPLE

FIG. 35.

it is therefore not on the market, but it is available for special research work. Within its capacity the instrument provides a photographic undistorted record of the object in any desired plane (Fig. 32).

Whereas in normal photography or profile projection a lens is employed to form the image " A " (Fig. 33) of an object " B," it is possible with certain restrictions to design a system in which " C " (Fig. 34) is a sharply defined image of " D," in spite of

SECTION PROJECTOR PRINCIPLE.

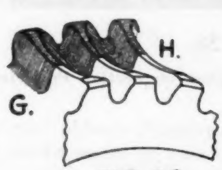


FIG. 36.

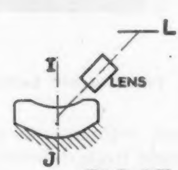


FIG. 37.

the fact that " C " and " D " are not parallel with one another, and this is the principle on which the Section Projector is based.

Fig. 35 is the same as Fig. 34 except that it is tipped up at 45°, so that an object placed at " E " will be sharply defined without distortion on a photographic plate at " F."

The instrument has an illuminating system which shines on to the object a clear-cut sheet of light, one edge of which defines a plane. Take, for example, the case of a worm wheel (Fig. 36). When placed in the instrument this is intersected by a sharply defined line G-H, which line can be adjusted until it lies in the plane of the desired section.

Fig. 37 shows the gear tooth with the section plane defined by I-J. The photographic lens is then placed in a position from which the surface of the gear tooth can be seen, and a photograph is taken on a plate at "L." (See also Fig. 38.) Some

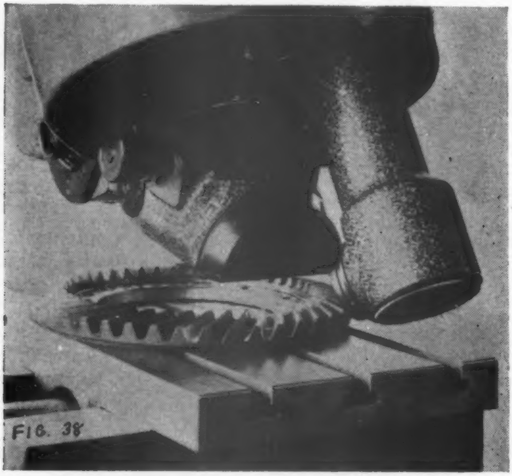


FIG. 38.

Crown wheel being photographed on Section Projector.

additional refinements in the instrument enable two exposures to be made from different points of view in cases where the whole of the section cannot be seen from one direction. The two photographic records will appear on one plate in correct relationship to one another. It is also possible to make two photographic records on one plate of, for example, a worm wheel and a worm, in order to see how they would engage with one another.

Doubt is sometimes expressed as to the value of the extreme accuracy which some optical instruments provide. Uncertainty

in engineering measurement leads to enormous waste, particularly where tolerances are small. If this is to be avoided, then the uncertainty of the measuring instrument should never exceed one-tenth of the working tolerance. Where there is uncertainty a good operator tends to restrict the working tolerance himself, as this is the only means of making sure that his work will pass inspection, while a less skilful operator working to the full tolerance will have some of his work rejected.

The operator's means of measurement should be, if anything, better than the inspector's, and it is very well worth while to place the accurate instrument in the shop, where it will result in substantial saving, rather than hide it away where it may be admired but seldom used.

The application of optics to engineering is likely to be much extended, in spite of the war, for although it has been true that much of the best optical equipment in the past has had to be obtained from abroad, great advances are being made in this country to provide British instruments with an even better performance than the pre-war imported products.

Discussion

Birmingham Section

(Owing to restrictions on the supply of paper, it is not possible to publish more than one of the discussions on Mr. Taylor's paper.)

MR. TUCK: Mr. Taylor has given us a very interesting talk on a subject with which most engineers are not very conversant. I would like to ask if anything has been done to develop a way of measuring the diameter of holes in the neighbourhood of $\frac{1}{8}$in. to $\frac{1}{10}$in.? He tells us of developments for indicating straightness, but the diameter and the roundness are a problem.

MR. ARCHER SMITH: What is the main difference between the projection microscope and the contour projector? You can get a microscopic view of an article from both instruments, and, to some extent, they seem to cover the same field. Another question is its relation to finishes. There is an increasing interest in finishes, which are measured in micro inches. Do optical instruments aid in the measurement of surface finish?

MR. MARK H. TAYLOR: First, Mr. Tuck's question regarding the measurement of the diameters of small holes. As I tried to point out, you can project the image of the end of a hole if the hole is at right angles to the surface in which it is drilled, but you cannot get a clearly defined image further down the hole, as it becomes confused by reflections from the surface, and because there is no clearly defined point which will give you a really clear image. Optics, therefore, is at a disadvantage in measuring shapes of holes other than the shape of the mouth of a hole. I do not think that optics can be regarded as the best means of dealing with this particular problem.

Regarding the difference between the projection microscope and contour projector, primarily the projection microscope is used for measuring or for giving an image of the surface of an object which is illuminated from the top, such as, for example, etched specimens. Generally speaking, the contour projector is used for producing a shadow image, which is produced, in effect, by an object placed between the light and the screen. Whichever device is used, if measurements are to be taken, then the optical system must be really free from distortion.

Concerning finish, there is a great battle going on at the present time over surface finish. The Research Department of the Institution is working on that subject, and has been examining a range of different types of instrument, some optical, some

electrical, some mechanical, for giving a measurement of surface finish. The report will be published shortly, and I can tell you it has been a terrific job.

It is very difficult indeed to judge the roughness of a surface by viewing it optically. A lapped surface which appears dull may easily be very much flatter than a polished surface which appears bright. I think it will be found that the devices which are not dependent primarily on optics prove to be the most reliable for this purpose.

Mr. J. W. Berry (Section President): I remember a lecturer in my early apprenticeship days who often spoke of the example of the man who used to go through the shop and say to his foreman turner "Is it near enough?" The man would say "Yes," and that was that! We have moved apace since those days. I begin to understand the attitude of some members of the machine tool trade when they resist our request for instructions on machine tools and alignments, when such instruments are available to check them up. The optical square intrigued me. We shall no longer be able to throw our weight about with the theory of Pythagoras, and show the foreman how to set out the factory. Referring to the lens for measuring screws, does that involve a special lens for each angle of thread?

Mr. Taylor: Referring to the special lens for measuring screw threads, one lens will deal with any helix angle up to 6°.

Mr. Gee: It struck me when a speaker mentioned the measurement of the inside of holes that you have got over a very difficult problem in curved gear teeth, and I wonder if it might be possible, by the same means, to measure the roundness of a hole part of the way down?

Mr. Taylor: I am not going to say it is impossible, but we have not found the way yet. In the case of a curved gear tooth the plane is defined, in effect, by a sheet of light which strikes the gear surface. In the case of a hole you would want to define the plane which is normal to the axis of the hole. If the hole is big enough for you to get a light inside it is possible, but most holes are not. The problem is not insoluble, I am sure, but we do not know the answer yet.

Mr. MacLaren: Mr. Taylor was born and has grown up in this illuminating atmosphere, of which he has given us an example to-night. He is really a very versatile man and a very modest man, because he has not told us half of what he could tell us. We see the terrific accuracy that is obtained by these delicate instruments. A few weeks ago I was taking the representative of a world-wide engineering firm over Mr. Taylor's works, where

a number of this firm's machines are installed. He expected to be complimented on his machines, but one of them had failed to produce the required accuracy, and an autocollimator was set up to show the reason for the trouble. The bed of the machine, if you please, was wearing at one end a little bit more than at the other.

Mr. Taylor's firm makes lenses for cameras, and I think I am right in saying that approximately 90% of the Hollywood films that you see in our picture houses to-day were taken with lenses made in Leicester. Some time ago his firm was offered, and undertook, the manufacture in this country of the electro-limit gauge, a particularly accurate instrument whereby a measurement can be taken in one room and observed a mile away if necessary. The applications of this instrument are very far-reaching. It can be applied to internal and external measuring on such machines as a rolling mill, turning out a plate from a piece of rolled steel. By means of the electrolimit gauge differences in the thickness of the metal being rolled can be checked up at the time the strip comes through the mill, with the result that a consistent thickness throughout is assured.

Mr. Taylor: In dealing with attempts to introduce really accurate measuring devices into industry, one of the greatest problems is the fear on the part of industry that too many defects will be shown up. It is very disappointing to come up against this fear, because it is associated with a wrong impression of what an accurate instrument is intended to do. If you are going to assume that because an instrument will measure to .0001in. (where the previous instrument measured to .001in.) it is necessary to start working to .0001in. instead of .001in., then I have every sympathy with the person who says "I do not want any of your instruments in our shop." But if you can really get over the idea that an immense amount of argument, trouble, and money can be saved by being able to measure to .0001in., at the same time leaving the tolerance at .001in., then you are introducing into your shops the very best that accurate instruments can give you.

Mr. Hawkins: It occurs to me that in future, when we desire to project objects, we should do well to obtain permanent records by means of the camera. In other words, we should photograph everything instead of projecting everything. Perhaps it would be too costly, but the way the helical gear wheel has been recorded photographically seems to be much more satisfactory than an image on a screen. Is it commercially possible to have the camera come into action every time we want to take a record of a profile?

MR. TAYLOR: Engineers do not like dark rooms, do not like developing plates, and do not like to wait for results, but I think there is little doubt that as time goes on the photographic method will be more generally used. People in toolrooms are very conservative—it is perhaps a very good thing they are, or they might find themselves encumbered with all sorts of things that were useless to them. They rightly take a great pride in their skill, but I am afraid in many cases they think that what was good enough for their grandfathers is good enough for them. All the same, as far as the photographic method is concerned, before it is more widely adopted in engineering we have to get to the point where photography as applied to any particular job of measurement offers such obvious advantages over any other method that engineers just cannot keep away from it. It is going to take time. I suppose we always have the example of certain progressive firms who are ready to introduce a new method into their shops, but it takes 10 years or more before such practice becomes general. The photographic method has great advantages, but it will have to be simplified and speeded up.

MR. ARCHER SMITH: On our projection microscope we have just taken a photograph of a punch for punching the eye in a needle. I believe the dimensions of that eye are about .004in. by .008in., more or less elliptical in shape. It is the practice of the men who work the machines which pierce the eyes in the needles to make their own punches, and they do not think anybody else can make them. We have been wanting to avoid the necessity for these men having to stop so long to prepare their punches, and we have been trying to get ready-made punches which they can put straight in the machine without losing time. We therefore got another department to make these punches. The position at the moment is that some punches are being prepared by specialists in very small work, and we have taken photographs of these and also of the ones made by the men who are going to use them, and who have previously made them. We intend to hand the two types of punch to the men on the machines and say "Here are your punches—try them out." We have formed our opinion from the photographs, and we shall be able to judge whatever their reactions are how much has been due to prejudice.

MR. TAYLOR: I am interested in the example you have described, and I should like, if I may, to stress how much care is necessary in introducing a new inspection technique into engineering. There are many psychological problems. A man who has had to work hard to acquire exceptional skill, and believes he is doing a really accurate job, quite naturally, and rightly, resents an unskilled person being so equipped with

scientific apparatus that he can prove inaccuracy in skilled work. Although these accurate measuring devices can be used by unskilled people, they should be introduced into the shop through the skilled man, so that they become means of proving how *good* a product a skilled man can produce, instead of proving how bad a job he can do.

Another point which it is impossible to overstress is the importance of providing the shop with even better testing equipment than the inspection department itself. Only when this policy is understood and practised can scrap be reduced to a minimum.

MR. SMART: What means exist of testing these instruments which are put in the hands of people who have to be educated in their use to ensure that they are maintained in accurate condition?

MR. TAYLOR: This is a very important point which has not yet received sufficient consideration. Optical instruments are frequently regarded as so mysterious that their performance is accepted as right without any means of checking being provided. In my opinion, the object of the manufacturer should be to provide means whereby the user can check that the instrument remains in adjustment.

MR. JACKSON: I hope my question is not too elementary. I am particularly interested in the profile of the gear teeth which Mr. Taylor showed us. May I ask how it can be checked for accuracy after you have photographed it?

MR. TAYLOR: The section projector takes an actual-size photograph of the gear tooth section, and this photograph is then projected on to a screen in a profile projector.

A cordial vote of thanks was tendered to Mr. Taylor.

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